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(71) Applicants *(for all designated States except US)*: **NEWLANDS TECHNOLOGY LIMITED** [GB/GB]; Unit 3E, Newlands Science Park, Inglemire Lane, Hull HU6 7TQ (GB). **PDD LIMITED** [GB/GB]; 87 Richford Street, London W6 7HJ (GB).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **GREENOUGH, Rodney, David** [GB/GB]; The Dell, 34 Church Lane, Bonby, North Lincolnshire DN20 0PS (GB). **PLANT, Colin, Edward** [GB/GB]; Meadowsweet Cottage, Hambledon Road, Denmead, Hampshire P07 6AQ (GB). **METHERINGHAM, William, John** [GB/GB]; Carr Farm, Hilston Road, Roos, East Yorkshire HU12 0JB (GB). **ASTON, Martin, Geoffrey** [GB/GB]; 4 Pasture Close, Market Weighton, East Yorkshire YO43 3QQ (GB). **JENNER, Alan, Gordon, Ian** [GB/GB]; 32 Westgate, North Cave, Brough HU15 2NJ (GB). **WILKINSON, Anthony, James** [GB/GB]; Alphaschloss, Station Road, Shiptonthorpe, York YO43 3PB (GB). **JOHNSON, David, Anthony** [GB/GB]; 2 Main Street, Kilnwick, Nr Driffield YO25 9JD (GB). **SMITH, Brian, Douglas** [GB/GB]; 15 Fairlawn Avenue, Chiswick, London W4 5EF (GB). **MUNNS, Neil** [GB/GB]; 161 Ella Street, Kingston upon Hull, East Yorkshire HU5 3AT (GB).

(74) Agent: **LOVEN, Keith, James**; Loven & Co, Quantum House, 30 Tentercroft Street, Lincoln LN5 7DB (GB).

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(54) Title: DUAL MODE AUDIO DEVICE

(57) Abstract: A self-contained device for inducing acoustic waves into a panel such that the panel radiates audible sound, the device comprising a casing (1) containing: (a) a power source, for example dry cell batteries; (b) an audiofrequency signal input (2) from an external signal source such as a personal stereo, or an audiofrequency signal generating means such as an audio player or a telephone; (c) an amplifier connected to the power source and to the signal input and providing an output signal; (d) an audiofrequency actuator (4) connected to the audio output circuit and adapted to couple acoustically with the panel when the device is brought into contact therewith.

DUAL MODE AUDIO DEVICE

Field of the Invention

This invention relates to a dual mode audio output device, to a hands-free cordless or mobile telephone, and to a novel magnetostrictive actuator suitable *inter alia* for use in such devices. The invention also provides a foetal stimulator, a security device, a communications system, a rear-view mirror for a motor vehicle, a display device, and a noise reduction device.

Background to the Invention

It is known that a panel may be made to function as a loudspeaker by attaching to the panel an audiofrequency actuator which can transmit acoustic signals into the panel. WO92/03024 discloses one such panel. WO98/52289 suggests the use of standard trim panels in a motor vehicle as a means of radiating the output of a radio, tape player or the like, listing magnetostrictive, electromagnetic, electrostatic and micromotor transducers as possible for the job, although preferring piezoelectric transducers.

While such panels can be made to operate as satisfactory loudspeakers, they all depend on attachment of the actuator to the panel, and the availability of mains power or a vehicle alternator output to drive them, for various reasons. Piezoelectric devices require high voltages and relatively large currents to produce suitable levels of audio power, while electromagnetic devices, although operating at low voltages, require very high currents to produce sufficient power to produce audible output from the panels. Magnetostrictive devices can generate a substantial force at a relatively low voltage, but have previously been impractical for portable domestic uses for two reasons. Firstly, the current consumption to generate the necessary magnetic fields to cause change in length of the magnetostrictive material is relatively high, and secondly, the cost of the magnetostrictive material, most commonly Terfenol-D, an alloy of the rare earth elements dysprosium and terbium with iron, with a chemical composition $Dy_{0.7}Tb_{0.3}Fe_{1.95}$, is very high, and the cost of a typical Terfenol-D rod, for example as disclosed in US-A-5406153, at 6mm diameter and 50mm length, and US-A-5880542, at 38mm diameter and 54mm length, would be prohibitive.

It has been found that simply scaling down conventional magnetostrictive actuators does not produce satisfactory audio output, with high levels of distortion or very low volume.

Referring to another aspect of the invention, it is common practice to carry out ultrasonic scanning of foetuses in their mothers' wombs to monitor their development and check for problems and abnormalities. This procedure is sometimes made more difficult or even impossible because the foetus is sleeping and in the wrong position for satisfactory scanning. It is then necessary to try to wake the foetus to cause it to move. This must be done in a manner that causes no distress or harm to the foetus or discomfort to the mother.

It has been proposed to play sounds to the foetus to wake it, and various devices have been considered for this purpose. A difficulty is that conventional loudspeaker devices do not concentrate the acoustic energy where it is needed; a relatively high external volume is required to achieve the necessary level within the womb, because the efficiency of sound transmission in the amniotic fluid is low, and a high level of external sound can be disturbing or annoying to others in the vicinity.

Referring now to yet another aspect of the invention, when conversations are carried on in a room, the sound waves generated impinge upon and cause corresponding vibrations in components of the room. This phenomenon can be employed to listen to the conversations remotely, thereby permitting confidentiality in the conversation to be breached. For example, if the room has a window, the audiofrequency vibrations in the glass can be detected remotely by directing a laser beam on to the external surface of the glass and detecting the variations in the phase of the light reflected back from the glass surface. This enables a substantial part of the original sound within the room to be reconstructed and listened to.

Even where no windows are present, it is possible to monitor sound within the room by placing a microphone or like transducer in contact with a non-rigid wall, ceiling or floor surface to detect audiofrequency vibrations induced into the surface.

Since confidential commercial information can be of considerable value, it is important to prevent breaches of confidentiality arising from industrial espionage, and there

is therefore a need for some means of masking the audiofrequency vibrations in room surfaces, preventing their being detected externally.

Summary of the Invention

According to one aspect of the invention, there is provided a self-contained dual mode device for inducing acoustic waves into a panel when in contact therewith such that the panel radiates audible sound, the device comprising a casing containing:

(a) a power source;

(b) an audiofrequency signal input;

(c) an amplifier connected to the power source and to the signal input and providing an output signal; and

(d) an audiofrequency actuator connected to the audio output circuit and arranged within the casing to produce a low level audio output which may be heard when the casing is brought adjacent to a user's ear, the actuator being adapted to couple acoustically with the panel when the device is brought into contact therewith, thereby producing an amplified audio output from the panel.

The input is suitably a standard plug socket permitting an external audio signal source such as a portable tape or CD player, a solid state memory device, or a mobile telephone, to be connected thereto by means of a connecting plug lead. Thus, for example, using the device of the invention, a personal audio device which normally outputs only to earphones or headphones can be made audible to a number of people at the same time, simply by placing the device on a panel surface such as a table, or attaching the device to a vertical surface such as a window. The device also provides the possibility of hearing the sound output by bone conduction. Placing the device against a bone or a tooth will permit the user to experience the sound as though it were emanating from within the body.

An alternative embodiment of the invention provides a self-contained dual mode device for inducing acoustic waves into a panel such that the panel radiates audible sound, the device comprising a casing containing

(a) a power source;

(b) an audiofrequency signal generating means;

(c) an amplifier connected to the power source and to the signal generating means and providing an output signal;

(d) an audiofrequency actuator connected to the audio output circuit and arranged within the casing to produce a low level audio output which may be heard when the casing is brought adjacent to a user's ear, the actuator being adapted to couple acoustically with the panel when the device is brought into contact therewith, thereby producing an amplified audio output from the panel.

In this way, the construction of an audio device may be adapted to permit the device to be used alternatively as a personal device when carried by the user, for example, and a shared device by the simple measure of placing the device on a panel surface, for example a table, or attaching the device to a vertical surface such as a window, by means of an integral sucker attachment, a re-usable adhesive strip, or a re-usable high tack material such as that sold under the Registered Trade Mark Blu-Tack, for example, or using a separate bracket which is permanently attached to the surface by means of adhesive, the device clipping into the bracket to hold it in contact with the surface when desired.

The power supply may be, for example, dry cell or rechargeable batteries, a solar cell, or a combination of solar cell and rechargeable batteries.

The audiofrequency actuator is preferably a magnetostrictive actuator comprising a magnetostrictive element and an electromagnetic coil associated therewith, the coil being connected to the amplifier so that the output signal causes the element to deliver an output force which is modulated by said signal, and means are provided for transmitting the output force to the panel when the device is brought into contact therewith.

Another aspect of the invention provides a magnetostrictive actuator, comprising a bar of magnetostrictive material, an electromagnetic coil surrounding the bar, a first permanent magnet located at one end of the bar with the south pole thereof directed towards the bar, a second permanent magnet located at the other end of the bar with the north pole thereof directed towards the bar, incompressible spacer means located between each magnet and the bar, said spacer means being of a material of low magnetic permeability, and magnetic circuit means extending from the outwardly-directed pole of the first magnet to the outwardly-directed pole of the second magnet.

With this configuration, it is possible to construct an effective magnetostrictive actuator which has a very small size and weight, for example less than 25g, and using only a small, and therefore less costly, quantity of magnetostrictive material. For example, a length of less than 10mm is suitable, and preferably less than 6mm, with a thickness of less than 4mm. In an audio device, such an actuator can still produce sufficient audio output to permit it to be heard by a number of people in a typical office environment, for example.

A further aspect of the invention provides a magnetostrictive actuator, comprising a bar of magnetostrictive material, an electromagnetic coil surrounding the bar, spring means mechanically loading the bar and at least one permanent magnet biasing the magnetostrictive material such that a modulating electrical signal applied to the coil and thereby applying a modulated varying magnetic field to the material produces a substantially proportional modulated change in length of the bar.

Magnetostrictive material such as Terfenol-D displays a relationship between magnetic field applied and elongation which will depend on the load applied. As may be seen from Figure 1, a series of curves may be drawn representing these relationships under different loads σ_1 - σ_5. To ensure maximum displacement in response to a change in magnetic field, one needs to select an operating curve which has a steep gradient, while to minimise distortion to the audio output, it is necessary to operate within as near a linear part of the curve as possible. By mechanically loading the bar of magnetostrictive material so that the best curve is selected, and by magnetically biasing the material so that the changes in magnetic field due to the modulation on the coil lie within a substantially linear part of that curve, satisfactory audio output can be achieved for even small bars of magnetostrictive material. In the graph, a suitable curve is represented by the loading σ_2, giving a steep gradient resulting in large change of strain for a relatively small variation in magnetic field applied (referred to as a "burst effect") over a substantially linear part of the curve. It will be understood that the graph is for illustrative purposes only, and is not intended to be an accurate representation of the characteristics of a particular material.

It will be appreciated that the term "bar" used herein in relation to magnetostrictive material is intended to include different cross-sections of material, from circular to

rectangular; the precise shape will depend on the processes used to divide a manufactured bar of Terfenol-D, for example resulting from the process described and claimed in US-A-4770704, into small "chips" usable in the devices of the invention. It is envisaged that the "chip" size will be smaller than 6mm in length and 3mm in thickness or width, where thickness or width is the maximum dimension of the cross-section of the chip.

Although the magnetostrictive actuator of the invention is especially applicable to audio applications, it will be appreciated that it will also be useful in other applications where high output from small size and precise frequency control are important.

Another aspect of the invention provides a cordless telephone handset having a microphone, a radio transmitter/receiver connected thereto, and audio output circuit connected to the transmitter/receiver, the handset also including an audiofrequency actuator connected to the audio output circuit and adapted to induce acoustic waves into a panel when the handset is brought into contact therewith such that the panel radiates audible sound.

Again, the audiofrequency actuator is most suitably a magnetostrictive actuator, preferably in accordance with the invention.

The cordless telephone handset may be of the type linked by radio (digital or analogue) to a base station which is wired to the public switched telephone network (PSTN). Cordless telephones of this general type are common in houses and offices. Alternatively, it may be an independent radio telephone, for example a cellular radio telephone. There have been some concerns about the use of such telephones, especially cellular telephones, and their possible effect on users' brains, since it is necessary to hold a source of microwave radiation, albeit weak radiation, close to the user's head to hear the output of the internal loudspeaker. While various "hands-free" solutions have been proposed, most require some electrical link between the telephone and an earphone, and this is thought by some to act as an antenna radiating towards the user's head. The telephone handset of the invention can be used in one mode conventionally, by bringing it into close proximity with the user's ear, or in an alternative mode as a loudspeaking telephone simply by placing it on a horizontal surface such as a table or similar panel, or by attaching it temporarily to an upright surface such as a window, for example by a separate mounting

bracket, by double-sided adhesive tape or using temporary adhesive material such as Blu-Tack®. The handset needs to be held in intimate contact with the surface for satisfactory acoustic coupling with the panel to occur, and the body of the handset will be designed to ensure that intimate contact can occur when the handset is simply resting on a horizontal surface, for example. An additional advantage of this property is that "conference calls" in which several people in the same room, for example, can participate in the same telephone call at the same time can be conducted without the need for special additional equipment. Since the actuator will still induce sound waves into the body of the handset, the handset may still be used in conventional manner when privacy is essential and conditions permit "hands-on" use. Further advantages arise from this property of the device. Since the body of the handset radiates sound waves of sufficient amplitude to permit the output to be heard when the handset is held near to the ear, precise positioning of the handset relative to the ear becomes unnecessary – with conventional handsets having holes in the body next to the loudspeaker, alignment of the holes with the ear is necessary to achieve adequate sound volume, and this position may not be convenient for the comfort of the user. A further advantage is that, since holes through the casing are no longer necessary, the casing can more readily be made waterproof or at least water resistant. This has advantages when applied to communications devices used in adverse environments, for example those used by the military or the emergency services.

It will be seen that the handset can be used in three main ways: spontaneously, as a hand-held device or one that permits communication through touch, or by simply resting the handset on a surface; short-term, by temporarily attaching the handset to a surface using double-sided adhesive or a temporary adhesive such as Blu-Tack®; or permanently, by adhering the device to a surface with a permanent adhesive, for example for car use where it is desired to ensure that any use will be on a hands-free basis, and not hand-held and therefore contrary to law. The latter case may be useful where the employer has a duty to ensure that the employee conforms with the law, and may have a legal liability where there has been failure to comply.

Yet another aspect of the invention provides a portable audio player, comprising a power supply supplying power to an audio signal generating means and to an amplifier

connected to said signal generating means, and an audiofrequency actuator connected to the amplifier and adapted to induce acoustic waves into a panel when the player is brought into contact therewith such that the panel radiates audible sound.

The audiofrequency actuator is suitably a magnetostrictive actuator and preferably one in accordance with the invention.

The portable audio player may incorporate a radio tuner, a CD-player, a tape player, a solid-state memory device such as may record compressed digital recordings, for example in MP3 or similar format, or a combination of these. As with the telephone, the player may permit shared listening, or listening without earphones, without the need for additional external loudspeakers.

Alternatively, the portable audio player may be a portable computer, such as a notebook computer or a personal digital assistant, or an Internet access device. In the case of a notebook computer or the like, the actuator may be mounted in protrusion from the underside thereof arranged to act as one of three support feet for the computer casing, so that when the computer is placed on a surface such as a desk, the actuator is brought into intimate contact with the surface (via the casing), to achieve acoustic coupling therewith. The weight of the computer assists in achieving suitable coupling in this manner.

The portable audio player may, in another alternative embodiment, be a portable games device, in which the sounds associated with the game may be reproduced by placing the device on a table or other panel. The games device may also be held in the hands so that a lower level of sound is still audible to the user near to the device. The actuator may also be used to provide vibrations and other sensations associated with the game play.

A still further aspect of the invention provides a door incorporating a signal generator for generating an audio signal identifying the location of the door, and actuating means for transmitting the audio signal to the surface of the door, whereby the door radiates an audible signal indicating the location of the door.

The acoustic coupling of the actuating means with at least a panel of the door causes a directional audible signal to be projected into the room, which will assist in guiding people in the room towards the door in low visibility conditions.

The audiofrequency actuator is suitably a magnetostrictive actuator and preferably one in accordance with the invention.

Since the actuator can be located within the door panel, it can be isolated from the adjacent rooms, thus protecting it from excessive temperatures and from water in the rooms, and thereby ensuring that it continues to operate for the rated fire resistance period of the door, for example.

The audio signal could be a simple identifying tone or series of tones, or it could be a speech message announcing, for example, "Emergency exit this way". The signal generator may be linked to a fire alarm system so as to be activated with it, or it may be triggered manually or automatically in response to heat or other indicators of potential emergency.

The actuator is preferably mounted with the radiating face thereof in direct contact with the surface, and more preferably bonded thereto using adhesive or the like. Alternatively, mechanical mounting of the device may be used, the radiating face of the actuator being simply pressed against the surface.

The audiofrequency signal source may be a radio receiver, for example receiving a locally-radiated signal from an adjacent transmitter (for example in the same room, or perhaps the same building), permitting wireless distribution of a speech or music signal to a number of devices in accordance with the invention, distributed around the room or around the building. The same signal may be distributed to all such devices, or different signals may be directed to individual devices. A common carrier frequency may be used for the radio signal, with the audio information digitally or otherwise encoded in or modulated on it, or each receiver may operate at its own frequency. Digital encoding on a common carrier radio frequency will be a more efficient use of the radio spectrum.

Another aspect of the invention provides a foetal stimulator comprising a magnetostrictive actuator, and signal generating means for supplying an audiofrequency signal to the actuator at an energy level sufficient to stimulate the foetus without causing harm.

The signal generating means preferably comprises an amplifier. The signal generator is preferably arranged to generate signals at audiofrequencies generally less than 500Hz, since foetal hearing is stimulated by two routes, firstly by bone conduction to the inner ear and secondly via the external and middle ear. The first of these is more efficient, but conduction determines in part which frequencies of audible sounds the foetus can hear, and these are generally below the 500Hz threshold.

The audio signal may be repetitive monotones, or short musical sequences, for example from well-known nursery rhymes or the like simple tunes. The musical sequences may be generated electronically or may be recordings of musical instruments and/or voices. The recordings may be magnetic tape recordings or on Compact Discs, but are suitably stored as digital recordings in solid state memory. The device may be arranged to be switchable between different types of signals and/or between different tunes.

Preferably, the actuator and signal generating means are mounted together in a single casing. More preferably, the casing also contains a power supply means such as a battery, so that the stimulator is entirely self-contained.

The advantages of using a magnetostrictive actuator are principally that, since it can be constructed as a low compliance force-generating device, it can be placed directly in contact with the mother's skin at the desired location and can launch sound efficiently into the amniotic fluid in the womb. It is typically a low-voltage device, and therefore intrinsically safe, and can be made compact and relatively low-powered so as to be usable in a small, hand-held, battery-powered device. The use of a self-contained hand-held device is advantageous in avoiding the need for trailing power leads, and permitting use of the device alongside portable scanning equipment outside a hospital environment.

The invention further provides a security device for attachment to a non-rigid surface in a room or the like, comprising a magnetostrictive actuator, and a signal generator for generating a substantially random audiofrequency signal encompassing the spectrum occupied by speech, the signal generator being connected to provide the audiofrequency signal to the actuator via an amplifier.

The actuator is preferably of the inertial type, since these can be constructed with a stiffness which is similar to that of the surface to which the device is to be attached, ensuring that the energy is coupled into the material of the surface efficiently. Such devices couple poorly to air, with the result that the random signal is not audible to occupants of the room, while ensuring that the noise signal completely overwhelms the vibrations due to speech in the room. It will be appreciated that the protection offered by the device of the invention becomes even more important when the speech in the room is amplified and broadcast by a loudspeaker system, for example when a large number of people in a hall are being addressed and it is desired to maintain confidentiality to the occupants of the hall.

The signal generator may be arranged to generate "white noise" – containing a random distribution of frequencies which on balance produce an even frequency distribution, but it is preferred to generate so-called "pink noise", in which the lower frequencies are boosted relative to the higher frequencies, as it has been found that the lower frequencies of speech predominate in the audio signal detectable in the vibration of the glass or other surface.

In the case of glass windows, it will typically be sufficient to install one such device on each window. For multiple-glazed windows, the actuator is preferably attached to the outermost glass pane, and is suitably installed between the panes of the window structure.

In the case of walls and other surfaces, it may be necessary to attach a number of the devices at intervals across the surface, either driving the actuators from a single signal generator via a single or multiple amplifiers, or providing each actuator with its own signal generator and amplifier. The latter arrangement offers higher security, since if all the actuators are provided with the same random signal, and any surfaces are able to vibrate independently of the others, it may be possible for the noise signal to be cancelled by comparison of two (or more) signals obtained from different surfaces.

The signal generator and amplifier may be located separately from the actuator, but in a preferred embodiment of the invention the security device is an integral unit containing the signal generator and the amplifier mounted in the same body as the actuator and attachable as a unit to the window or other room surface. An external electrical

power lead will need to be provided, since for permanent applications, battery power will be impractical. In either case, the device is mounted with the radiating face thereof in direct contact with the surface, and preferably bonded thereto using adhesive or the like. Alternatively, mechanical mounting of the device may be used, the radiating face of the actuator being simply pressed against the surface.

The actuator is suitably designed as a low-compliance device whose stiffness matches that of the surface to which it is to be attached. The actuator propagates stress waves into the surface which generate a diaphragm movement in the window. Any attempt to monitor the surface for speech signals, either by remote laser techniques in the case of windows, or by microphones attached to wall surfaces, will yield only the white or pink noise signal, from which extraction of the desired signal is extremely difficult or impossible.

It has been found that the device of the invention can provide very effective masking of vibrations induced in windows and other surfaces by speech within a room, thereby preventing detection of the speech.

In yet another aspect of the invention, a rear-view mirror unit for a motor vehicle, comprises a mirror mounted as a front face of a hollow casing, the casing having audio input means connected to a magnetostrictive actuator in contact with the rear face of the mirror and arranged to couple acoustically with the mirror thereby outputting sound therefrom.

The audio input means, which is preferably connected to the actuator via an amplifier, may comprise a connecting socket, for example to permit connection, via a suitable lead and plug, to a mobile telephone, permitting hands-free operation thereof in a motor vehicle, the mirror unit serving as a loudspeaker. The mirror unit may also include a microphone.

Alternatively, the mirror unit may include radio receiving means, for example of the type permitting connection to a mobile telephone or the like via a short-range radio link, one example of which might be that known under the trade mark Bluetooth.

Another way of connecting to a mobile telephone would be by way of an infra-red link, for example of the type used to connect peripheral devices to computers.

Other panels within the passenger compartment of a motor vehicle may be combined with the actuator to provide a sounder for reproducing sound audibly within the passenger compartment. For example, the sun visor for the front windscreen or windshield may be used, or a transparent screen overlying the instrument panel of the dashboard.

The invention further provides a display device comprising a surface for displaying information, an audiofrequency actuator acoustically coupled to said surface for inducing into said surface acoustic waves causing the surface to radiate audible sound, storage and playback means connected to said actuator for replaying a recorded audio signal, and sensor means for detecting the presence of a person in proximity to the surface and for causing operation of the storage and playback means to send an audio signal to the actuator in response to said detection.

Thus, for example, a public advertising display may be arranged to deliver an audible message to supplement or reinforce the message displayed visually on the display surface, which may be a static display such as a poster, or a dynamic display such as a video display, for example. The display device responds to the presence of a person in proximity to the device; what constitutes proximity will be determined by the location and the type of information being displayed and made audible, for example.

The actuator is preferably a magnetostrictive actuator, and is more preferably of the type as defined and claimed herein.

A still further aspect of the invention provides a noise reduction device comprising a body mountable on to a window or like surface in a room, the body containing a microphone for monitoring sound within the room, control means for generating an antiphase signal corresponding to at least a selected component of the monitored sound, an amplifier for amplifying the antiphase signal, and an audiofrequency actuator connected to the amplifier and acoustically coupled to the window when the body is mounted thereon, whereby the acoustic signal coupled into the window causes a reduction in sound level in the room.

Thus, for example, the device may be arranged to reduce specific noise within the room, for example machine noise, which can be tiring or harmful to those exposed to it for long periods of time.

Again, the actuator is preferably a magnetostrictive actuator, and is more preferably of the type as defined and claimed herein.

In yet another aspect of the invention, a helmet or hard hat has an audiofrequency actuator acoustically coupled therewith, and is provided with means for supplying an audiofrequency drive signal to the actuator.

The means for supplying the audiofrequency signal may be a link to a separate radio communications device, or it may comprise a radio incorporated into the helmet. Such a helmet may be useful for fire fighters, permitting messages to be heard clearly in adverse conditions, since the helmet radiates sound around the head, permitting it to be heard without blocking out, or being blocked out by, ambient sound.

Brief Description of the Drawings

In the drawings, which illustrate the background to the invention and exemplary embodiments thereof:

Figure 1 is a graph showing the variation of strain with applied magnetic field for a typical magnetostrictive material for a range of different biasing forces applied to the material;

Figure 2 is a cross-sectional diagrammatic view of an audio device according to one embodiment of the invention;

Figure 3 is a cross-sectional diagrammatic view of a mobile telephone in accordance with another embodiment of the invention;

Figure 4 is a cross-sectional diagrammatic view of a magnetostrictive actuator according to a preferred embodiment of the invention;

Figure 5 is a cross-sectional diagrammatic view of a foetal stimulator according to another aspect of the invention;

Figure 6 is a diagrammatic representation of a security device in accordance with a further aspect of the invention, attached to a window;

Figure 7 is a diagrammatic representation of an alternative security device;

Figure 8 is a cross-sectional diagrammatic view of an audio player in accordance with another embodiment of the invention;

Figure 9 is a cross-sectional diagrammatic view of a vehicle rear-view mirror in accordance with yet another embodiment of the invention;

Figure 10 is a cross-sectional diagrammatic view of a section of a door in accordance with another embodiment of the invention;

Figure 11 is a diagrammatic plan view of a room having the door of Figure 10;

Figure 12 is a plan view of a floor of a building having a communications system installed therein in accordance with the invention;

Figure 13 is schematic side elevation of a display device in accordance with the invention; and

Figure 14 is a schematic sectional view through a helmet in accordance with another aspect of the invention.

Detailed Description of the Illustrated Embodiments

Referring first to Figure 2, the audio device comprises a casing 1 contains batteries 2, typically replaceable dry cells or rechargeable cells, and an electronic circuit 3 including an amplifier powered thereby. An input socket 4 receives a connector plug, for example a miniature jack plug, on a connector lead to an external signal source, for example a personal stereo player, a mobile telephone or the like. The electronic circuit 3 within the audio device comprises a squelch circuit which detects the presence or absence of an input signal and switches the amplifier to a quiescent state when no signal is present to preserve battery life. The casing 1 has mounted therein a magnetostrictive actuator 5, for example of the type described hereinafter with reference to Figure 4. The actuator is connected to the amplifier output so that the magnetostrictive material changes its length in response to the audiofrequency signal output by the amplifier. The actuator is in intimate contact with the casing 1, which in turn can be brought into close contact with the surface of a panel such as a table 6, for example, or a window, so as to couple with the surface acoustically, inducing an acoustic wave within the panel. This causes the panel 6 to radiate sound.

Figure 3 shows a cellular radio telephone comprising, in conventional manner, a casing 10, containing a battery 11, a main circuit board 12 with electronic components 13, 14 and 15 thereon, a liquid crystal display screen 16, a keypad 17, a microphone 18, and an antenna 19. In place of the conventional loudspeaker, a magnetostrictive actuator 20 is mounted within and in contact with the casing 10, and is connected to the amplifier section of the main circuit board, which is adapted to provide a suitable driving output for the actuator 20.

In use, the telephone can be used in conventional manner (the first mode), being held to the side of the face so that the microphone is adjacent to the mouth, while the actuator part of the body is adjacent to the user's ear. The actuator 20 will in these conditions cause the casing 10 to radiate sufficient sound energy to permit the user to hear its output in the conventional way, so the exact positioning of the handset relative to the ear is not critical. For hands-free or conference use, however, the telephone may be placed on a panel such as a table 21 (the second mode). The actuator 20 then couples the acoustic energy into the panel, causing it to radiate the sound at a level sufficient to enable the sound to be heard in the vicinity thereof. A conventional microphone will typically have sufficient sensitivity to pick up speech and other sound from the vicinity, but automatic gain control may ensure that the sensitivity is adjusted to suit the circumstances of use, so that the sound volume transmitted by the telephone is not excessive when the telephone is used conventionally.

It will be seen that an advantage of the telephone of the invention is that there is no need for any adaptation or adjustment to change from hand-held to hands-free use and *vice versa*; the adaptation is automatic as a result of the dual mode capability of the telephone.

Figure 4 shows a schematic cross-section through a magnetostrictive actuator in accordance with a preferred embodiment of the invention. A small element 40 of Terfenol-D is mounted between two high-powered button magnets 41 and 42, with spacers 43 and 44, for example of brass, spacing the poles of the magnets from the ends of the element 40. The magnets are arranged such that one magnet has its north pole directed towards the element 40, while the other magnet has its south pole directed towards the

adjacent end of the element. Surrounding the assembly of magnets, spacers and the element is an electromagnetic coil 45 arranged to cause a varying magnetic field to flow axially through the element 40 in response to the application thereto of a modulating signal, which may be an audiofrequency signal. The electromagnetic coil 45 is wound on a plastics former 45a, which also serves to encase and position the magnets 41 and 42, the spacers 43 and 44 and the element 40. A steel cylinder 46 encloses the coil and provides the outer path of the magnetic circuit through the element 40. One end of the magnet/spacer/element assembly 40-44 carries the weight of the coil 45 and cylinder 46 via the former 45a, while the other end has a pusher cap 47, which is suitably formed of aluminium, steel or a plastics material, bearing against it. The pusher cap 47 is held in position in the cylinder 46 by a steel circlip 48 which is received in a groove 49 around the inside of the cylinder 46, while a wavy spring 50 is mounted between the circlip 48 and the pusher 47 to exert a biasing pressure on the end of the assembly 40-44 sufficient to ensure that the optimum relationship exists between the magnetic field applied and the elongation of the element 40. A typical pressure applied would be of the order of 5-8MPa. In use, the weight of the coil and cylinder assembly provides a reaction force, so that when the pusher is in direct or indirect contact with a surface and a modulating signal is applied to the coil, the modulated force generated by the element is transmitted directly to the surface.

Referring now to Figure 5, the foetal stimulator comprises a casing 51 dimensioned and arranged to be conveniently held in one hand, in use. The casing 51 contains in a lower part thereof a magnetostrictive actuator 52 and in an upper part an electronic circuit 53 comprising a signal generator and an amplifier, linked through a control lead 54 to the actuator. A battery 55 supplies electrical power to the circuit 53 via a switch 56 which is operable by applying pressure to a resilient portion of the casing 1 to cause the device to operate.

The actuator 52 is of the inertial type, having a central rod 57 of Terfenol-D material which engages at the upper end thereof a hollow weight 8 surrounding the rod 57 and at the lower end a force transmitting member 59 moulded into a containing body 60. The weight 58 is held as a close sliding fit within the body 60 by means of O-rings 61 lo-

cated in circumferential grooves around the weight. An actuating coil 62 is located within the hollow part of the weight and around the rod 57 so as to apply the control magnetic field thereto. Biasing permanent magnets may be provided around the rod 57, in conventional manner.

The signal generator part of the electrical circuit 53 is arranged to provide a tone or series of tones at audible frequencies generally below 500Hz to drive the actuator. In use the device is held with the actuator pressed against the mother's abdomen above the womb and is switched on to transmit the tone or series of tones to the sleeping foetus in the womb, causing the foetus to wake up and to move to a position in which it can be "seen" by the ultrasonic scanning device. An additional switch may be provided to select the tone or the sequence of tones (or tune) to be played by the device. The operation of the device may be limited to a predetermined length of time, such that pressing the "on" switch causes operation for that length of time only after which the device automatically switches off.

Referring next to Figure 6, the device comprises a magnetostrictive actuator 71 bonded to the inner surface of a glass window 72 by means of an adhesive and connected by a cable 73 to a signal generator 74 via an amplifier 75. It will be understood that the signal generator 74 and the amplifier 75 may be contained within a single casing which can be located adjacent to or remote from the window. A power lead 76 supplies electrical power to the signal generator and amplifier.

The signal generator 74 is arranged to generate "white noise", a random audiofrequency signal in which the frequency distribution is, on average, uniform across the audible spectrum. Such white noise signal generators are well-known, and do not therefore require detailed description. Since the lower frequencies in speech have greater effect in causing vibration of window and wall surfaces than higher frequencies, these frequencies predominate in any speech signal recovered from such a surface by remote surveillance means, and it may therefore be desirable to use a signal generator in the device of the invention which produces "pink noise", i.e. a white noise signal in which the lower frequencies are boosted in amplitude relative to the higher frequencies.

Figure 7 illustrates an alternative device in which the separate components of the system of Figure 6 are integrated into a single body which can be attached to the window (or wall) surface by means of adhesive, and which requires only an electric power supply cable leading to it. The device comprises a housing 80 mounted on a magnetostrictive actuator 81 whose radiating face 82 is bonded to the surface of the window 83 by means of adhesive. The housing contains electronic circuitry 84, typically in the form of a single circuit board with discrete components mounted thereon, comprising the signal generator and amplifier which provide the driving signal to the actuator.

In the audio player illustrated in Figure 8, a housing 90 contains a disc player such as a Compact Disc player or MiniDisk player, shown diagrammatically at 91. The construction of such players is well-known and is therefore not shown or described in detail. The casing also contains batteries 92, typically replaceable dry cells or rechargeable cells, and an electronic circuit 93 including an amplifier powered thereby. The casing 1 has mounted therein a magnetostrictive actuator 95, for example of the type described hereinbefore with reference to Figure 4. The actuator is connected to the amplifier output so that the magnetostrictive material changes its length in response to the audiofrequency signal output by the amplifier. The actuator is in intimate contact with the casing 90, which in turn can be brought into close contact with the surface of a panel such as a table 96, for example, or a window, so as to couple with the surface acoustically, inducing an acoustic wave within the panel. This causes the panel 96 to radiate sound. It will be understood that other audio sources may readily be substituted for the disc player 91, for example an FM or other radio receiver, a tape cassette player, or a solid state audio storage and playback device.

In the rear-view mirror unit shown in Figure 9, the mirror 100 is held in the open front face of a housing 101 which is mounted via a bracket 102 to the vehicle windscreen or to the inner roof surface above the windscreen. The mirror will typically be mounted within the housing 101 in a swivel mechanism to permit it to be adjusted to avoid glare from following headlights; this mechanism is omitted from the Figure for the sake of clarity, as it has no effect on the features of the invention. The casing 101 contains an electronic circuit board 103 mounting electronic components providing *inter alia* an amplifier,

connected to a magnetostrictive actuator 104 which is mounted in intimate contact with the rear face of the mirror 100, for example by means of adhesive. Power is supplied to the circuit board 103 from the vehicle's electrical system through a supply lead 105 which runs through the mounting bracket 102. A microphone 106 is mounted within the housing so as to receive sound from within the vehicle's passenger compartment, and this is then connected to the circuit board via a connecting cable 107. The circuit board 103 is also connected via a further cable 108 to a socket 109 opening through the housing. The socket 109 permits connection via an external lead and plug (not shown) to a cellular telephone in such a manner that speech received by the microphone 106 is sent to the telephone to be transmitted in the usual way, while speech received by the telephone is passed via the amplifier on the circuit board 103 to the magnetostrictive actuator 104, which then couples acoustic energy into the mirror, causing it to radiate sound within the vehicle passenger compartment so that it is audible to people sitting in the compartment. In this way, the mirror unit can permit hands-free operation of the telephone, with the sound emanating from a location adjacent the windscreen of the vehicle, ensuring that the driver's attention is not distracted from the road. There is a risk that sound from another direction will tempt the driver to look towards the source of the sound in a conversation, and thus divert attention from the road ahead, and the mirror unit according to the invention avoids this happening.

Figure 10 illustrates an emergency door in accordance with another aspect of the invention. The door 110 is of hollow construction, with two outer skins 111 and 112 spaced apart on a framework (not shown), and with fireproof insulating material 113 between the skins. A magnetostrictive actuator 114 is mounted on the skin 112 which faces into the room, in use, so as to couple acoustically therewith. The actuator 114 is connected to a controller device 115 which includes a memory storing a digitally recorded message, for example "Emergency door this way". The controller device 115 includes an amplifier to provide an audiofrequency output at sufficient power to drive the actuator to couple an acoustic signal into the door skin 112, thereby causing the door surface to radiate into the room a directional audible announcement. Power for the controller device can be supplied by mains electric supply, although it may be desirable for the controller to

include a trickle charge battery charged while mains power is available, and arranged to power the device to make the audible announcement in the event of a power failure as well as in response to an alarm signal sent from a central control, for example. Figure 11 shows the door 116 installed in a room 117. In an emergency, the door radiates the audible announcement directionally into the room, enabling a person 118 in the room to be guided towards the door, which is the emergency escape route, even if lighting has failed or the room is filled with smoke.

Figure 12 illustrates a communications system for a building, for example permitting speech transmitted from one room to be heard in a selected one of the other rooms, or in all rooms. The system comprises a base station 120 located in one room 121, and a receiver 122 mounted on the window 123 in each other room 124. The base station 120 comprises a microphone and means for transmitting a radio signal carrying addressing coding indicating which of the receivers is to be addressed (for a general announcement, this may be all receivers, or a selected group of receivers). Each receiver 122 includes a radio receiver and a magnetostrictive actuator, for example in accordance with the invention, arranged within the receiver so as to couple acoustically with the window to cause the window to radiate sound into the room . It will be appreciated that each room could also be provided with a base station permitting two-way communication.

Figure 13 shows an advertising or like display device comprising an advertising display panel 130 having detector means 131 mounted thereon, for example a passive infra red detector, to detect the presence of a person 132 adjacent to the panel. In response to detection of the person 132, the detector means signals to an announcement device 133 which causes a recorded message to be played via a magnetostrictive actuator coupled to the rear face of the panel. The actuator is suitably of the type described herein, being small and cheap to manufacture, while giving acceptable sound quality and volume. The announcement may enhance the message displayed on the panel, or give location or other information.

The helmet shown schematically in Figure 14 is, for example, a fire fighter's helmet (it will be appreciated that the Figure does not seek to provide an accurate representation of any particular such helmet). The helmet comprises an outer hard shell 140 and

inner padding or webbing 141 to space the wearer's head from the shell and to render the helmet comfortable to wear. A magnetostrictive actuator 142 is mounted in the space between the wearer's head and in contact with the outer shell 140 so as to couple acoustically with the shell. In this way, the whole of the shell can be made to radiate an audio signal, for example a radio message, in such a way that the wearer can hear the message while at the same time hearing ambient sound. The actuator may be connected to an external radio device, but in the embodiment illustrated, a small radio device 143 is mounted within the helmet and is connected via a lead 144 to the actuator 142.

CLAIMS

1. A self-contained device for inducing acoustic waves into a panel such that the panel radiates audible sound, the device comprising a casing containing:

(a) a power source;

(b) an audiofrequency signal input;

(c) an amplifier connected to the power source and to the signal input and providing an output signal;

(d) an audiofrequency actuator connected to the audio output circuit and arranged within the casing to produce a low level audio output which may be heard when the casing is brought adjacent to a user's ear, the actuator being adapted to couple acoustically with the panel when the device is brought into contact therewith, thereby producing an amplified audio output from the panel.

2. A self-contained device for inducing acoustic waves into a panel such that the panel radiates audible sound, the device comprising a casing containing

(a) a power source;

(b) an audiofrequency signal generating means;

(c) an amplifier connected to the power source and to the signal generating means and providing an output signal;

(d) an audiofrequency actuator connected to the audio output circuit and arranged within the casing to produce a low level audio output which may be heard when the casing is brought adjacent to a user's ear, the actuator being adapted to couple acoustically with the panel when the device is brought into contact therewith, thereby producing an amplified audio output from the panel.

3. A device according to Claim 1 or 2, wherein the audiofrequency actuator is a magnetostrictive actuator comprising a magnetostrictive element and an electromagnetic coil associated therewith, the coil being connected to the amplifier so that the output signal causes the element to deliver an output force which is modulated by said signal, and means are provided for transmitting the output force to the panel when the device is brought into contact therewith.

4. A device according to Claim 2 or Claim 3 as dependent on Claim 2, wherein the signal generating means is a player device for reproducing a recorded audiofrequency signal.

5. A device according to Claim 4, wherein the player device is a recording tape player, a CD player, a DVD player, or a solid state memory device.

6. A device according to Claim 2 or Claim 3 as dependent on Claim 2, wherein the signal generating means is a radio receiver.

7. A device according to Claim 6, wherein the radio receiver is a radio telephone.

8. A device according to Claim 6, wherein the radio receiver is a broadcast radio receiver.

9. A device according to Claim 6, wherein the radio receiver is a receiver for a locally-radiated radio signal, for example providing a wireless connection from a local signal source.

10. A magnetostrictive actuator, comprising a bar of magnetostrictive material, an electromagnetic coil surrounding the bar, a first permanent magnet located at one end of the bar with the south pole thereof directed towards the bar, a second permanent magnet located at the other end of the bar with the north pole thereof directed towards the bar, incompressible spacer means located between each magnet and the bar, said spacer means being of a material of low magnetic permeability, and magnetic circuit means extending from the outwardly-directed pole of the first magnet to the outwardly-directed pole of the second magnet.

11. A magnetostrictive actuator, comprising a bar of magnetostrictive material, an electromagnetic coil surrounding the bar, spring means mechanically loading the bar and at least one permanent magnet biasing the magnetostrictive material such that a modulating electrical signal applied to the coil and thereby applying a modulated varying magnetic field to the material produces a substantially proportional modulated change in length of the bar.

12. A magnetostrictive actuator according to Claim 10 or 11, wherein the length of the bar is less than 10mm.

13. A magnetostrictive actuator according to Claim 10, 11 or 12, wherein the width of the bar is less than 4mm.

14. A cordless telephone handset having a microphone, a radio transmitter/receiver connected thereto, and audio output circuit connected to the transmitter/receiver, the handset also including an audiofrequency actuator connected to the audio output circuit and adapted to induce acoustic waves into a panel when the handset is brought into contact therewith such that the panel radiates audible sound.

15. A cordless telephone handset according to Claim 14, wherein the audiofrequency actuator is a magnetostrictive actuator.

16. A cordless telephone handset according to Claim 15, wherein the magnetostrictive actuator is an actuator according to any of Claims 10 to 13.

17. A cordless telephone handset according to Claim 14, 15 or 16, which is a cellular radio telephone.

18. A cordless telephone handset according to any of Claims 14-17, comprising means for removably securing the handset to a surface in such a manner that the actuator is held in contact with the surface, thereby permitting acoustic coupling therewith.

19. A portable audio player, comprising a power supply supplying power to an audio signal generating means and to an amplifier connected to said signal generating means, and an audiofrequency actuator connected to the amplifier and adapted to induce acoustic waves into a panel when the player is brought into contact therewith such that the panel radiates audible sound.

20. A portable audio player according to Claim 19, wherein the audiofrequency actuator is a magnetostrictive actuator.

21. A portable audio player according to Claim 20, wherein the magnetostrictive actuator is an actuator according to any of Claims 10 to 13.

22. A portable audio player according to any of Claims 19 to 21, comprising means for removably securing the player to a surface in such a manner that the actuator is held in contact with the surface, thereby permitting acoustic coupling therewith.

23. A door incorporating a signal generator for generating an audio signal identifying the location of the door, and actuating means for transmitting the audio signal to the surface of the door, whereby the door radiates an audible signal.

24. A door according to Claim 23, wherein the actuating means is a magnetostrictive actuator.

25. A door according to Claim 24, wherein the magnetostrictive actuator is an actuator according to any of Claims 10 to 13.

26. A foetal stimulator, comprising a magnetostrictive actuator, and signal generating means for supplying an audiofrequency signal to the actuator at an energy level sufficient to stimulate the foetus without causing harm.

27. A foetal stimulator according to Claim 26, wherein the signal generator comprises an amplifier.

28. A foetal stimulator according to Claim 26 or 27, wherein the signal generator is arranged to generate signals at audiofrequencies less than 500Hz.

29. A foetal stimulator according to Claim 26, 27 or 28, wherein the audio signal consists of repetitive monotones, or short musical sequences.

30. A foetal stimulator according to Claim 29, comprising means for generating the musical sequences electronically.

31. A foetal stimulator according to Claim 29, comprising means for reproducing musical recordings.

32. A foetal stimulator according to Claim 31, wherein the musical recordings are magnetic tape recordings or on Compact Discs.

33. A foetal stimulator according to Claim 31, wherein the musical recordings are stored as digital recordings in solid state memory.

34. A foetal stimulator according to any of Claims 26 to 33, which comprises means for switching between different types of signals and/or between different tunes.

35. A foetal stimulator according to any of Claims 26 to 34, wherein the actuator and signal generating means are mounted together in a single casing.

36. A foetal stimulator according to Claim 35, wherein the casing also contains a power supply means.

37. A security device for attachment to a non-rigid surface in a room or the like, comprising a magnetostrictive actuator, and a signal generator for generating a substantially random audiofrequency signal encompassing the spectrum occupied by speech, the signal generator being connected to provide the audiofrequency signal to the actuator via an amplifier.

38. A security device according to Claim 37, wherein the signal generator is arranged to generate "white noise" containing a random distribution of frequencies which on balance produce an even frequency distribution.

39. A security device according to Claim 37, wherein the signal generator is arranged to generate "pink noise", in which the lower frequencies are boosted relative to the higher frequencies.

40. A security device according to Claim 37, 38 or 39, wherein the signal generator and amplifier are located separately from the actuator.

41. A security device according to Claim 37, 38 or 39, comprising an integral unit containing the signal generator and the amplifier mounted in the same body as the actuator and attachable as a unit to the window or other room surface.

42. A security device according to any of Claims 37 to 41, wherein the actuator is designed as a low-compliance device whose stiffness matches that of the surface to which it is to be attached.

43. A communications system comprising a base station including a microphone and means for broadcasting a local radio signal carrying the audio output of the microphone, and a plurality of remote units, each remote unit being attached to a respective window in a building and having a radio receiver for selectively receiving the broadcast signal and for outputting an audio signal to an actuator arranged to couple acoustically with the window, thereby rendering the audio signal audible in the region of the window.

44. A rear-view mirror unit for a motor vehicle, comprising a mirror mounted as a front face of a hollow casing, the casing having audio input means connected to a magnetostrictive actuator in contact with the rear face of the mirror and arranged to couple acoustically with the mirror thereby outputting sound therefrom.

45. A rear-view mirror unit according to Claim 45, wherein the audio input means is connected to the actuator via an amplifier.

46. A rear-view mirror unit according to Claim 44 or 45, wherein the audio input is a connecting socket.

47. A rear-view mirror according to Claim 44 or 45, wherein the audio input comprises a radio receiver.

48. A rear-view mirror according to Claim 44 or 45, wherein the audio input comprises an infra-red receiver.

49. A rear-view mirror according to any of Claims 44 to 48, wherein the magnetostrictive actuator is an actuator according to any of Claims 10 to 13.

50. A rear-view mirror according to any of Claims 44 to 49, which also includes a microphone.

51. A display device comprising a surface for displaying information, an audiofrequency actuator acoustically coupled to said surface for inducing into said surface acoustic waves causing the surface to radiate audible sound, storage and playback means connected to said actuator for replaying a recorded audio signal, and sensor means for detecting the presence of a person in proximity to the surface and for causing operation of the storage and playback means to send an audio signal to the actuator in response to said detection.

52. A display device according to Claim 51, wherein the audiofrequency actuator is a magnetostrictive actuator.

53. A display device according to Claim 52, wherein the magnetostrictive actuator is an actuator according to any of Claims 10 to 13.

54. A noise reduction device comprising a body mountable on to a window or like surface in a room, the body containing a microphone for monitoring sound within the room, control means for generating an antiphase signal corresponding to at least a selected component of the monitored sound, an amplifier for amplifying the antiphase signal, and an audiofrequency actuator connected to the amplifier and acoustically coupled to the window when the body is mounted thereon, whereby the acoustic signal coupled into the window causes a reduction in sound level in the room.

55. A noise reduction device according to Claim 54, wherein the audiofrequency actuator is a magnetostrictive actuator.

56. A noise reduction device according to Claim 55, wherein the magnetostrictive actuator is an actuator according to any of Claims 10 to 13.

57. A helmet or hard hat having an audiofrequency actuator acoustically coupled therewith, and means for supplying an audiofrequency drive signal to the actuator.

58. A helmet or hard hat according to Claim 57, wherein the audiofrequency actuator is a magnetostrictive actuator.

59. A helmet or hard hat according to Claim 58, wherein the magnetostrictive actuator is an actuator according to any of Claims 10 to 13.

60. A motor vehicle having a passenger compartment which comprises at least one panel having an audiofrequency actuator acoustically coupled thereto and means for providing an audiofrequency modulated driver signal to the actuator.

61. A motor vehicle according to Claim 60, wherein the panel is a movable sun visor for the windscreen or windshield.

62. A motor vehicle according to Claim 60, wherein the panel is a transparent screen overlying the instrument panel of the dashboard.

63. A motor vehicle according to Claim 60, 61 or 62, wherein the audiofrequency actuator is a magnetostrictive actuator.

64. A motor vehicle according to Claim 63, wherein the magnetostrictive actuator is an actuator according to any of Claims 10 to 13.

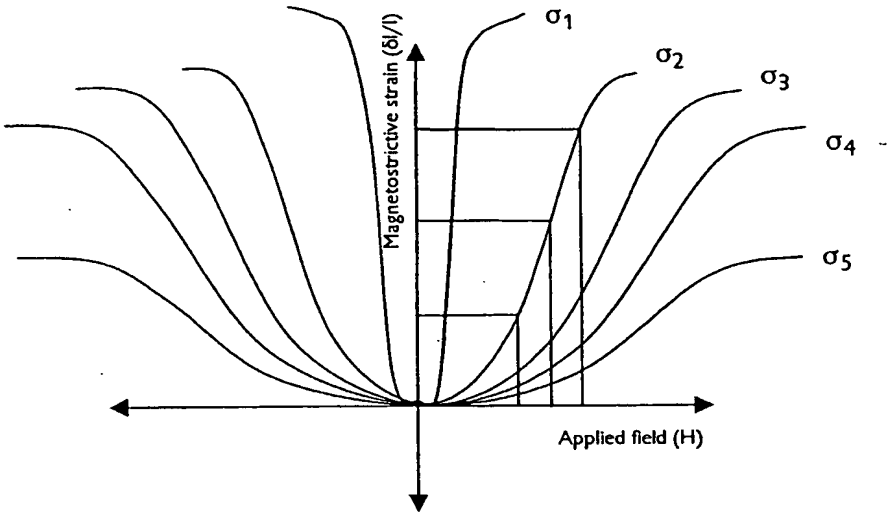
σ1
σ2
σ3
σ4
σ5
Magnetostrictive strain (δl/l)
Applied field (H)

Fig 1

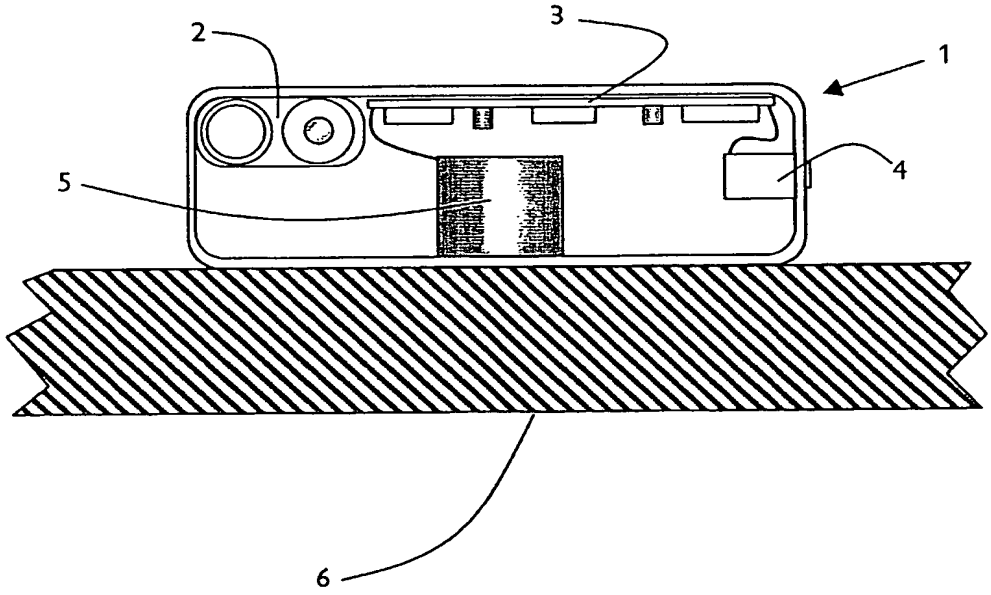
1
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Fig 2

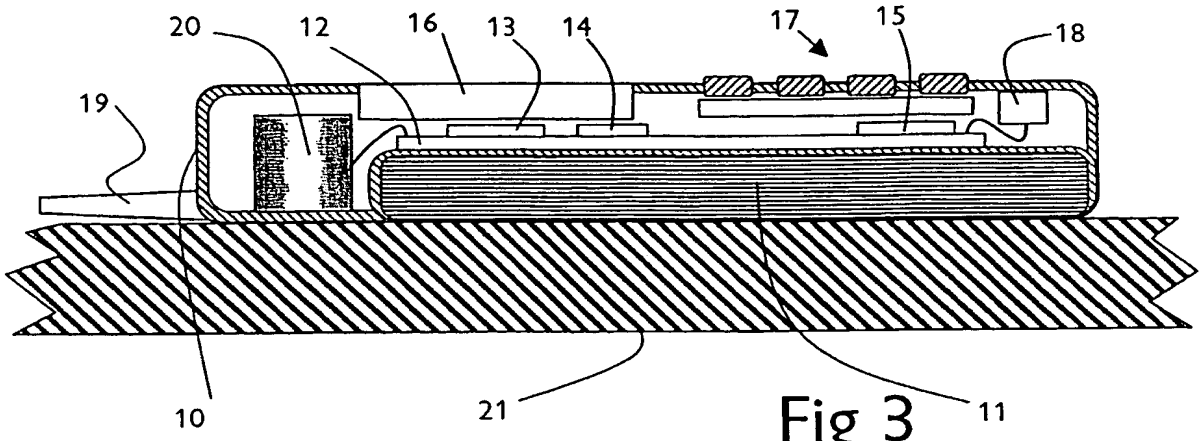

Fig 3

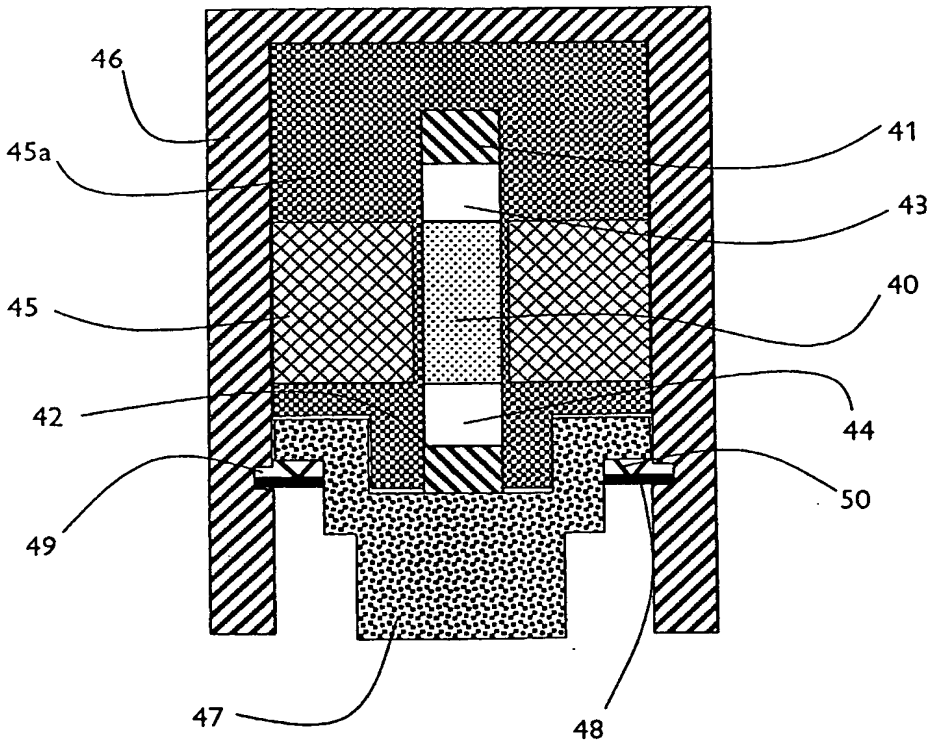

Fig 4

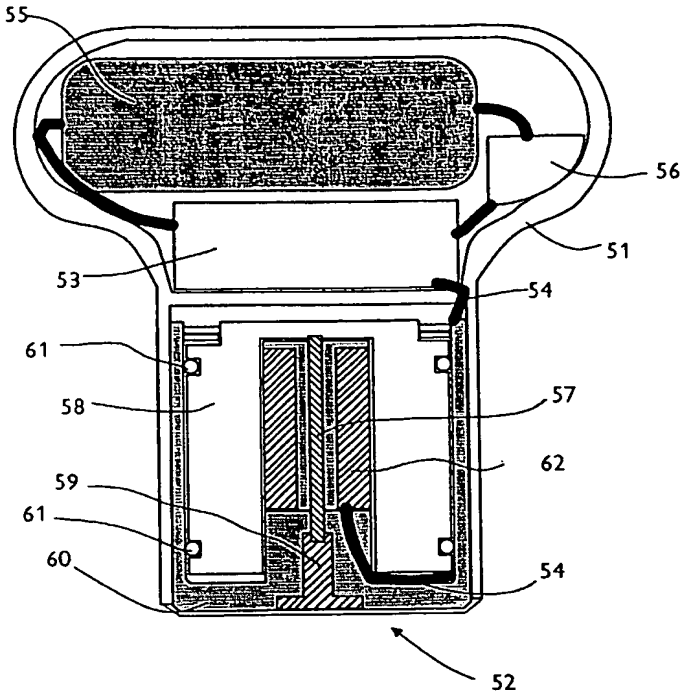

Fig 5

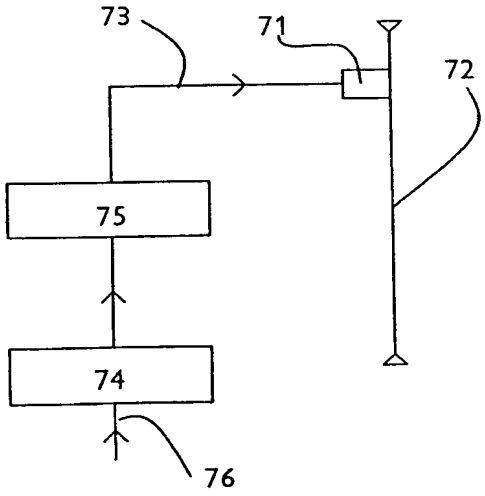

Fig 6

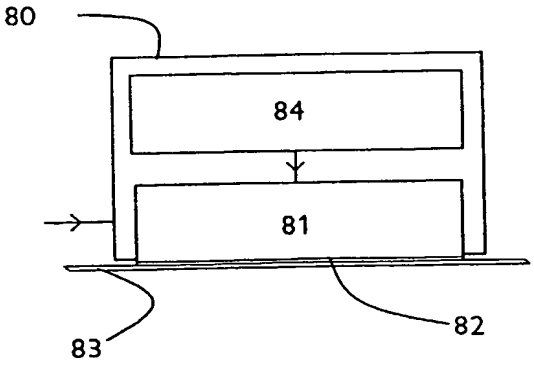

Fig 7

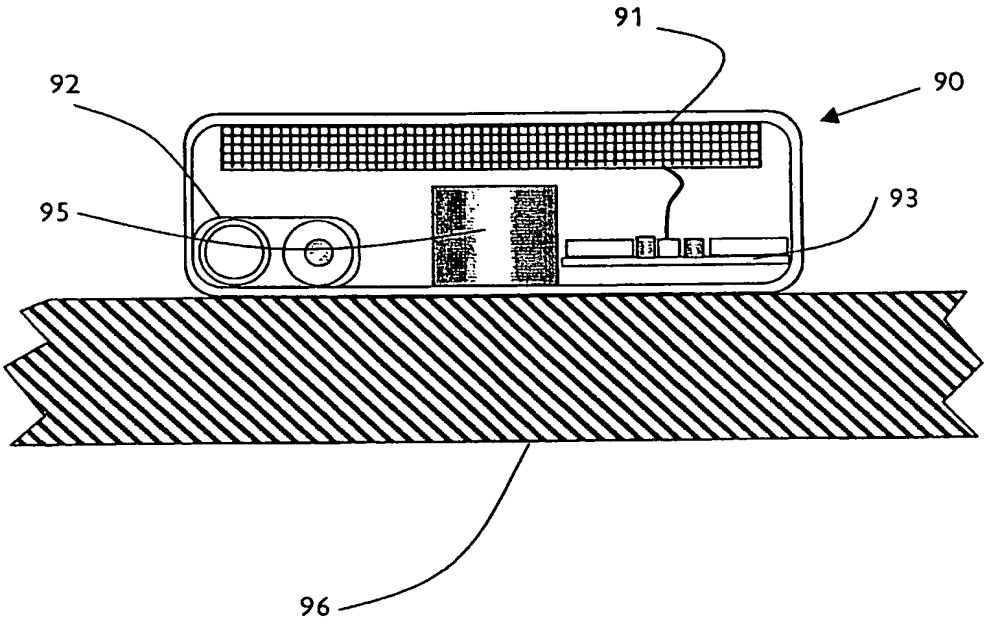

Fig 8

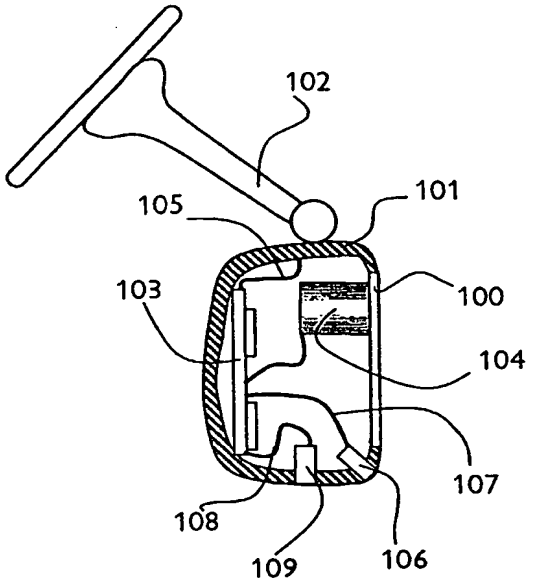

Fig 9

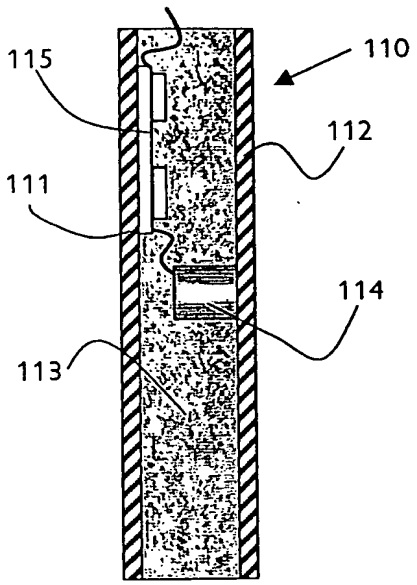

Fig 10

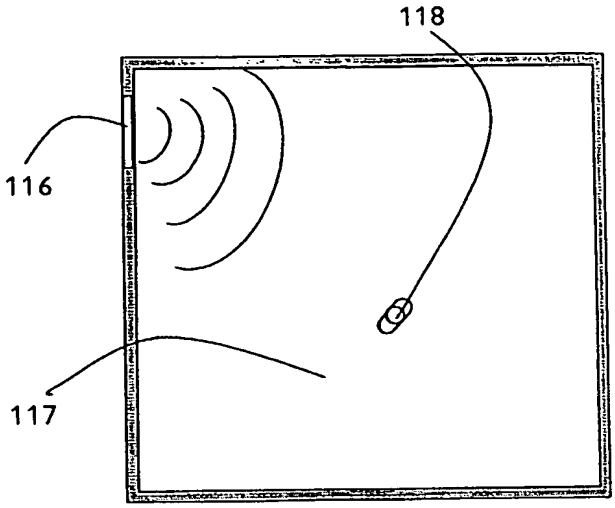

Fig 11

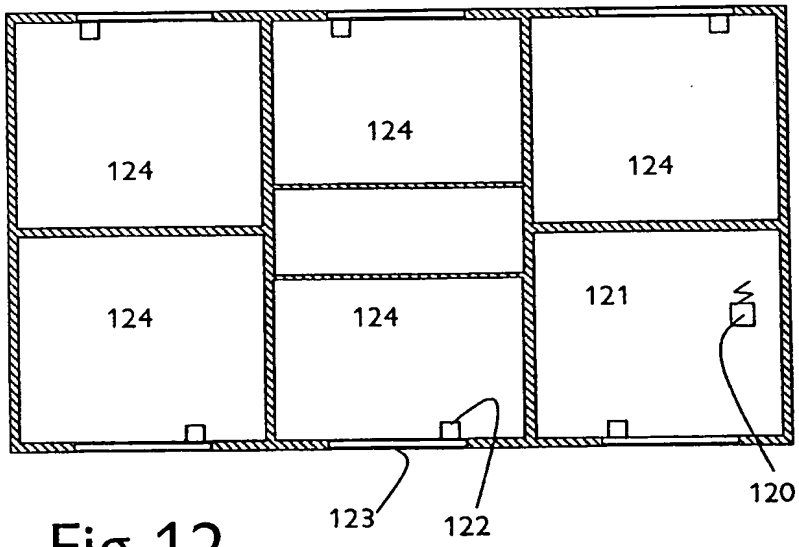

Fig 12

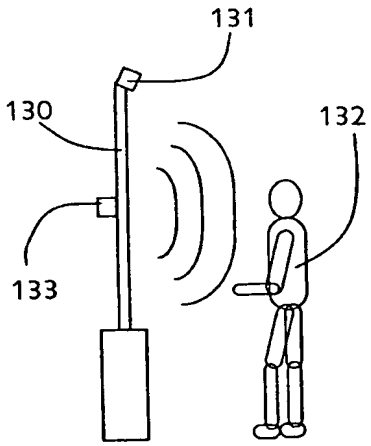

Fig 13

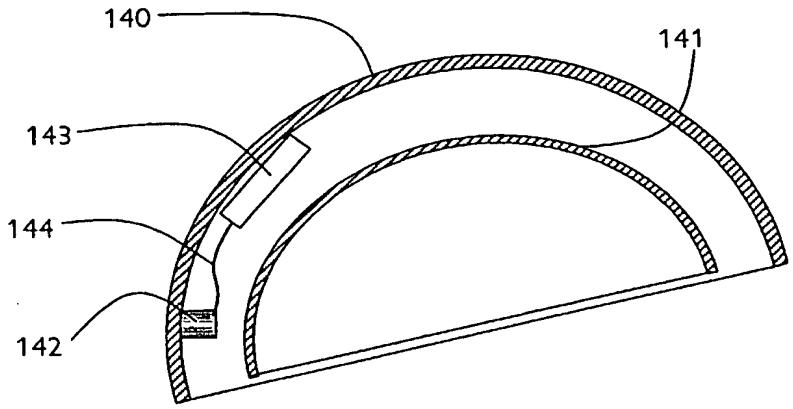

Fig 14